**Faculty of Engineering**

# Experiment and Simulation of High Pressure Die Casting Using ADC12 Aluminium alloy for Porosity Defect Prediction

**Mohd Rosli Bin Mohamad**

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# Experiment and Simulation of High Pressure Die Casting Using ADC12 Aluminium alloy for Porosity Defect Prediction

Mohd Rosli Bin Mohamad

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# DECLARATION

I declare that the work in this thesis was carried out in accordance with the regulations of Universiti Malaysia Sarawak. Except where due acknowledgements have been made, the work is that of the author alone. The thesis has not been accepted for any degree and is not concurrently submitted in candidature of any other degree.

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Signature

Name: Mohd Rosli Bin Mohamad

Matric No.: 18020044

Faculty of Engineering

Universiti Malaysia Sarawak

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# ABSTRACT

This research analysis was carried out in a manufacturer of domestic die casting for the automotive industry, manufacturing Power Steering Rack Housing aluminium alloy primarily for domestic and international markets. Defects in die casting caused by molten metal when it filling the mould are gas or air trapping porosity, and shrinkage porosity. However, the controls of casting flaws or defects were depending on the know-how of die casting experts, and it is also based on a trial and error of experimentation. Trial and error of experimentation usually required a longer pace plus a highly expensive price which finally results in high rejection rates. This research present numerical simulations which analysed the molten ADC12 aluminium alloy filling flow, metal solidification behaviour and a predicted porosity over transformation during the heat transmission process from liquidus condition to solidus condition by using a 3-D numerical simulation on a computer. The numerical simulation recreated the real parameter setting conditions on the die casting unit, the mould gates design, the runner, the air vents, and the mould cooling system. The numerical findings are confirmed throughout assessments with the experimental casting result investigation. Results suggested a noteworthy assurance in the ability to predict porosity by casting numeric simulation. A shrinkage porosity position is precisely determined by significant correlations between numerical mould filling simulation and casting solidification behaviours. The findings of the numerical research clearly show that the last point of solidification on the die-casted part was the area where shrinkage porosity can be found, the last point on casting to solidify was significantly was the thickest area on the die-casted part and the last point on casting to solidify was the hot spot area of the die-casted part.

**Keywords:** Numerical simulation, mould filling, aluminium high pressure die castings, shrinkage porosity

***Simulasi Aliran Komputer Tekanan Tinggi Simulasi Pengisian Cetakan dan Ramalan Kecacatan Keliangan***

## *ABSTRAK*

*Kajian penyelidikan ini dijalankan di pengeluar komponen automotif tempatan yang menghasilkan aloi aluminium Power Steering Rack Housing untuk pasaran tempatan dan global. Kecacatan acuan tuangan yang disebabkan oleh logam lebur semasa pengisian acuan termasuk liang gas, liang pengecutan dan udara terperangkap. Walau bagaimanapun, selama ini ujian yang dilakukan ke atas komponen automotif adalah cuba jaya berdasarkan kesilapan. Eksperimen cuba jaya dan kesilapan memakan masa dan adalah mahal yang akhirnya membawa kepada kadar penolakan atau pembuangan yang tinggi. Kajian ini membentangkan simulasi berdasarkan analisa aliran pengisian logam lebur, tingkah laku pemejalan logam dan ramalan liang melalui perubahan semasa proses pemindahan haba dari bentuk cecair ke bentuk pepejal menggunakan simulasi komputer 3-D. Simulasi mewakili keadaan sebenar tetapan parameter pada mesin die castings, acuan, pelari, liang dan reka bentuk penyejukan. Hasil berangka disahkan melalui perbandingan dengan pemerhatian yang dilakukan pada eksperimen. Keputusan menunjukkan keyakinan yang ketara ke atas kemampuan simulasi untuk memprediksi keliangan atau liangi. Lokasi keliangan atau liang adalah tepat di jangka melalui hubungan yang ketara antara simulasi berangka pengisian acuan dan pemasaan. Penemuan kajian numerikal ini jelas menunjukkan bahawa titik pemejalan terakhir di bahagian die cast adalah kawasan di mana liang pengecutan telah dijumpai, titik terakhir pada pemutus untuk mengukuhkan adalah dengan ketara adalah kawasan paling tebal di bahagian acuan tuangan dan titik terakhir pada pemutus untuk menguatkan adalah kawasan tempat panas bahagian acuan.*

***Kata kunci:*** *Simulasi berangka, pengisian acuan, aluminium acuan tuangan bertekanan tinggi, liang pengecutan*

**TABLE OF CONTENTS**

# LIST OF TABLES

## LIST OF FIGURES

# LIST OF ABBREVIATIONS

| | |
|---|---|
| A | Area normal to flow, $m^2$ |
| Al-Si | Aluminium silicon |
| APQP | Advanced Product Quality Planning |
| Cp | Specific heat |
| D | Divergence |
| d2 | Secondary dendrite arm spacing |
| FEA | Finite Element Analysis |
| fL | Volume fraction of liquid |
| g | Acceleration due to gravity, $ms^{-2}$ |
| IP | Intellectual Properties |
| JIS | Japanese Industrial Standard |
| k | Permeability of the medium |
| NADCA | North American Die Casting Association |
| $\rho$ | Density |
| $P_s$ | Shrinkage pressure |
| $\rho_L$ | Density of liquid |
| $q^n$ | Heat flux, $Wm^{-2}$ |
| SKD61 | JIS G 4404 grades of hot work mould steel |
| T | Temperature, Kelvin |
| u | Velocity trajectory in x direction of $ms^{-1}$ |
| UBE | Die casting machine brand |
| v | Velocity trajectory in y direction of $ms^{-1}$ |

| | |
|---|---|
| w | Velocity trajectory in z direction of $ms^{-1}$ |
| x | Distance, m |
| λ | Thermal conductivity, W/mK |
| 3-D | Three-dimensional |

# CHAPTER 1

# INTRODUCTION

## 1.1 Study Background

This research study was carried out in a manufacturer of local die casting for the automotive industry, manufacturing Power Steering Rack Housing aluminium alloy primarily for local and international markets. Defects in die casting caused by molten metal when it fills the mould contain porosities of gas or air trapping, and porosities of shrinkage. Control of casting defects was therefore dependent on the know-how of die casting engineers and their experiments in testing and error. Trial and error studies are required longer time consumption and it is an expensive method, which in the end leading to higher rejection rates. In the past decade, a lot of research has been focused on the numerical simulation of metal filling behaviours and molten metal solidification behaviours.

This thesis presents a numerical simulation that studied the filling flow of molten aluminium ADC12 alloy, the behaviours of metal solidification and the predicted porosities over the transformation in the heat transfer process from liquid to solid forms with the help of a 3-D computer numerical simulation. The main purpose of this study is to predict porosity using a numerical simulation. The numerical simulation reproduced the real die casting process criterion setting condition of the die casting machine unit, gating of mould, runner, air ventilation and cooling system. The numerical results are confirmed via a comparison with the casting experiments observations. Results suggested a noteworthy assurance in the capability of numerical simulation to predict or estimate the porosity of casting. A shrinkage porosities position is foreseen precisely and the is a significant association between computational simulation of mould filling and casting solidification behaviour. This research will increase the productivity of the mass manufacture of die casting manufacturing with the development of high accurateness of the simulation to predict a porosities defect, the knowledge of porosities defect study and the resolution of the defects. This can be done in the early phases of die casting moulding and die casting criterion design, which conventionally depends on a trial and error approach.

## 1.2 Problem Statement

The typical methods of die casting firms in Malaysia to get rid of porosity's defects were depending on trial and error innovation and modification of a die casting mould design. In general, past project experiences are used for upcoming implementations of projects. As the die casting methods and the die-casted products are becoming ever more complicated, it became too challenging to continue the method of trial and errors. This results in a lot of waste of die cast products and manufacture time.

The research has is being conducted at the local die casting company of Hicom Diecastings Sdn Bhd. The porosity defects have contributed to the highest waste and the highest cost of poor quality. The rejection was at 8.3% which been recorded in the year 2018 compared to their target which is at 3%. The losses or total cost of poor quality recorded in the year 2018 was at RM1.4 million. This loss has affected the company financial performance, increase the cost of operation and the product supply to the customer.

The North American Die Casting Association (NADCA) and Wilson (1997) has described die casting as a manufacturing process for the development of precisely shaped, clearly formed, smooth or coarse metal parts. It is achieved by driving molten into recyclable metal dies or moulds under high pressure. It is achieved by driving molten into reusable metal dies or moulds under high pressure. The high pressure die casting method is composed of three main stages as shown in Figure 1.1. In this research, Magmasoft ® computer simulation software has been used to foresee the porosities of die-casted goods in the Power Steering Rack Housing. In casting simulation, the study of mould filling, solidification and porosity formation is performed using an algorithm or program based on the finite volume method. The simulation programs are also focused on an analysis of the finite elements of 3-D casting models. Model casting must be produced using a solid modelling system and are imported into the simulation program. The input of numerical data replicates the real process criterion, gate, runner design, cooling design, overflows, air ventilation and mould structure. The 3-D and the actual mould layout design comparison can show in Figure 1.2. The numerical simulation result is then be confirmed by an experimental study on the real cold chamber high die casting machines and die casting mould. The predictive porosity accurateness is afterwards compared with the real porosities found on the die-casted sections.

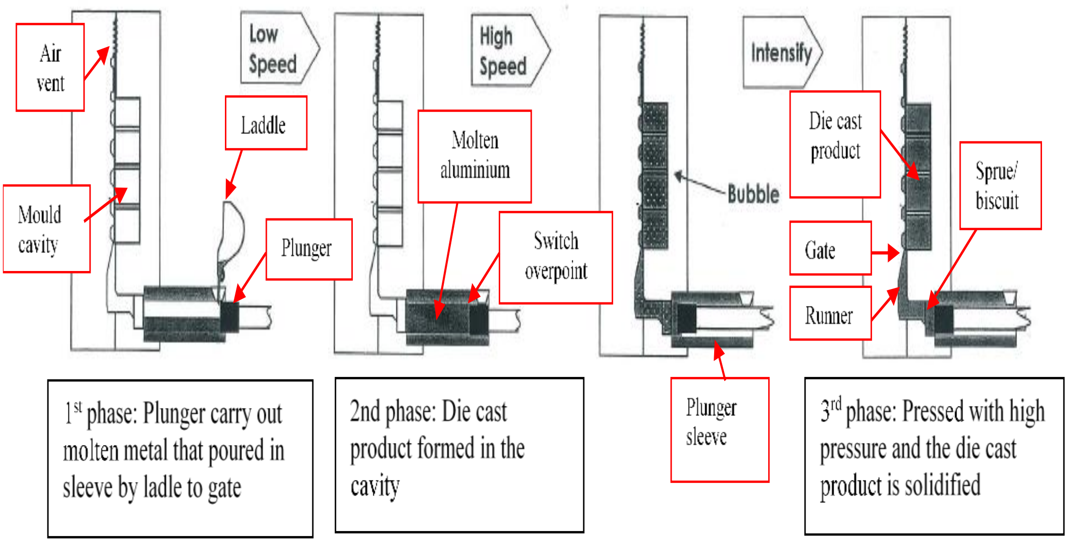


**Figure 1.1:** Phases of the cold chamber high pressure die casting

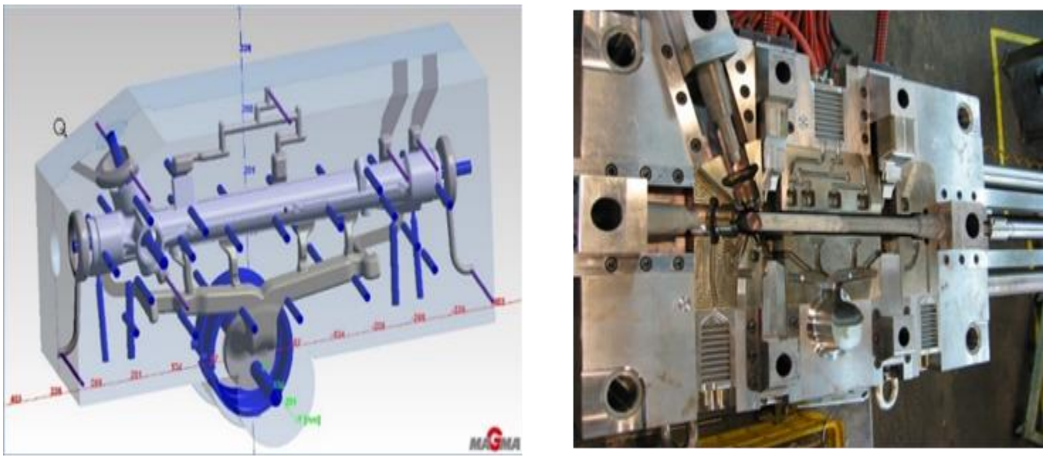

**Figure 1.2:** The power steering rack housing 3-D geometry model resembles the real moulding state

## 1.3 Objectives

Analysis from experimental and numerical simulation result can avoid trial-and-error process, the porosity defect location and types of porosity on die cast Power Steering Rack Housing can be predicted accurately and unnecessary cost on the wrongly designed mould. Analysis from experimental and numerical simulation can provides an information and the solution to overcome the porosity defects can be done effectively during the early stages, especially at the design stage. This will reduce the waste of doing corrective action during the production stage. If effective and correct methods to overcome porosity defects be implemented, then the rejection rate at Hicom Diecasting Sdn Bhd can be reduced. This also gives a direct impact of reduction on the cost of poor quality and indirectly impact on the cost of avoidance such as cost of reproduction the die cast, raw materials cost and premium freights. The aims of this research was to predict a type of and porosity defect and porosity defect location using numerical simulations of ADC12 aluminium alloy molten filling flows, casting solidification and the porosity formation for the Power Steering Rack Housing high pressure die cast. Developed an effective solution to resolve porosity defects found on the

Power Steering Rack Housing die cast and reduced a casting rejection and cost of poor quality due to porosity defect and meeting the target of 3% in of casting rejection in 6 months at the die castings manufacturer which is Hicom Diecastings Sdn Bhd. The specific objectives were:

1. Executes a numerical simulation to analyze ADC12 aluminium alloy metal flow and metal solidification.
2. Validates the porosity predicted in the numerical simulation with a porosity defect found in the experiment.
3. Assessed the porosity predicted in the numerical simulation to determines the type of porosity defect that occurred in the Power Steering Rack Housing die cast.
4. Evaluated a correlation of numerical simulation of the molten filling flow and molten solidification with the porosity formation.
5. Validate the numerical simulation against experimental data for the Power Steering Rack Housing die cast product as shown in Figure 1.3.
6. Produced 500 pieces of die cast samples on the die casting manufacturer facility to find a correlation between ADC12 aluminium alloy solidification behaviour and porosity formation for high pressure die cast products of Power Steering Rack Housing.
7. Performed a crosscut and x-ray fluoroscopic inspection to identify the correlation between shrinkage porosity formation and castings thickness for die cast products of Power Steering Rack Housing.